

NIOSH PPT Program Evidence Package Aug 30, 2007

Appendix D [Back to the Appendices Table of Contents](#)

Strategic Goal 3: Reduce Exposure to Injury Hazards

Appendix D discusses PPT Program research activities associated with the strategic goal for reducing exposure to injury hazards. These injury related activities are located separate from Chapter 5 because they are an integral component of other NIOSH programs undergoing review by the National Academies. These Programs include Hearing Loss, Traumatic Injury, and Construction. These activities are included for completeness and to indicate the comprehensive nature of the PPT Program, but should not be reviewed.

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Appendix D. Reduce Exposure to Injury Hazards

NIOSH conducts research activities designed to address knowledge gaps and improve existing technologies to reduce exposure to injury hazards. The specific projects related to injury hazards are dispersed across the NIOSH organization. They are conducted primarily as a part of the activities of other NIOSH sector and cross-sector programs, but are directly supporting the development of advanced PPT. These activities are included for completeness and to indicate the comprehensive nature of the PPT Program, but should not be reviewed.

Hearing Loss Exposure

The core PPT Program initiatives to reduce hearing loss exposure arise from the NIOSH Hearing Loss Research (HLR) Program that has had a component related to Hearing Protection Devices (HPDs).

Although NIOSH advocates the use of PPE only in the absence of effective engineering and administrative controls, sometimes HPDs are the only practical option for control of exposures to noise hazards.

Multiple external factors affect the use of HPDs. These factors include psychosocial barriers to hearing protection device use, injury latency times, comfort issues, and compliance issues. The PPT Program strives to recognize the external factors that provide challenges to the program, and to adapt in constructive ways that lead to progress or alternative research opportunities even in the face of those challenges.

Fall Exposure

The core of the PPT Program initiatives to reduce occupational fall exposures arises from the Traumatic Injury (TI) Program fall prevention research program initiated in 1995. The current PPT-related emphases of the TI program are fall-arrest harnesses and stability- and balance-enhancing protective footwear. Although current and future fall protection and protective footwear research efforts will be conducted within the NIOSH TI Program, these activities will be addressed in both PPT and TI Program goals.

Planning, information exchange, targeted research, teamwork, and information dissemination activities will be aligned in both the PPT and the TI Programs. In this chapter, we will refer to this component of the program as the PPT/TI Program.

Vibration Isolation Gloves

The PPT Program conducts research to reduce exposure to hand-arm vibration injuries. The research is focused on developing vibration isolation devices to reduce hand-arm vibration syndrome.

As with its other goals, the PPT Program takes four tactical approaches for accomplishing this goal:

- Conduct research on personal injury protection technologies.
- Develop standards for personal injury protective equipment.
- Evaluate personal injury protective equipment.
- Conduct outreach programs for optimal use and acceptance of personal injury protective equipment by workers.

The narratives that follow describe some significant outputs and outcomes to meet each objective.

D.1 Develop Measurement and Rating Methods That are Representative of the Real-World Performance of Hearing Protection Devices. (Strategic Goal 3, Objective 2)

Issue

Using the EPA's 1981[1] estimates of noise-exposed workers and current DOL statistics of U.S. production workers, approximately 13.5 million workers in the United States wear or should wear HPDs.[2], [3] Every HPD has a Noise Reduction Rating (NRR) to guide employers and workers as to which HPDs are sufficiently protective for different workplace conditions. The current EPA regulation specifies that the ANSI S3.19-1974 is the only acceptable experimenter-fit protocol standard for hearing protection devices for determining the NRR. [4] However, results by PPT scientists have shown that NRR results using this standard overestimate the level of protection achieved in the workplace by most users, resulting in workers being overexposed to noise.[5]

Approach

The PPT Program verified the overestimates of experimenter-fit NRRs in tests of HPDs in occupational settings. They demonstrated that the measurement of attenuation for experimenter-fit protector's yield inflated NRRs. The experimenter strives to achieve the highest possible NRR and repeatable results in the lab through excellent HPD fit. However, most workers who wear HPDs lack similar motivation and training. Unlike the experimenters, they are often unaware that compromised HPD fit reduces its attenuation.

In cooperation with the EPA to revise the existing labeling regulation, the PPT Program organized and conducted research on test protocols and rating methods through partnerships with government agencies and manufacturers, and active participation with standards setting bodies. In 1988, the EPA sought technical assistance from the PPT Program with a regulatory audit for labeling of a particular HPD. This audit resulted in a re-labeling of the HPD and initiated a broad research effort to develop testing methods that were more representative of workers' use. Between 1990 and 1994, the PPT Program executed two inter-laboratory studies that included six testing laboratories from government, industry, and academia. The studies demonstrated that a subject-fit protocol reduced inter-laboratory variability compared to inter-laboratory variability using other fit methods, including the experimenter-fit protocol.[5-7] In 1997, NIOSH established an inter-agency agreement with EPA. The initial work phase was to develop testing and rating methods for passive and electronically augmented hearing protectors. Since 2002, the PPT Program has provided the EPA technical assistance with the goal of issuing a revised regulation on HPD labeling.

The PPT Program collaborates nationally and internationally to influence hearing protector testing practices, performance ratings, testing standards, and regulations worldwide. Our scientists participated in the National Hearing Conservation Association (NHCA) Taskforce on hearing protection testing 1995, [8] which first recommended the use of a subject-fit protocol following the completion of the inter-laboratory studies. Since 1990, PPT scientists have been active in ANSI S12 working groups for standards development related to hearing protector testing and rating. In 2003, 2005 and again in 2006, PPT Program staff members were appointed

as United States delegates to International Standards Organization (ISO) and International Electronics Commission (IEC) technical committee meetings for international standards development of hearing protection testing and rating.

Output and Transfer Highlights

The inter-laboratory studies resulted in four peer-reviewed publications. [5-7],[9] The first of these papers reported that the subject-fit protocol had the smallest inter-laboratory variability. The other papers compared the real-world performance with the subject-fit protocols, examined models for describing HPD attenuation data, and established statistical methods for the analysis of subject sample size to achieve adequate reliability.

In addition to these papers, PPT Program scientists wrote papers for 14 conference proceedings, presented them, and sponsored conferences and workshops on hearing protectors. The PPT Program organized and provided technical support for the EPA's 2003 workshop on hearing protector labeling regulation. This conference brought together representatives from nine HPD manufacturers (3M, Aearo, Bilsom, Bose, Gentex, HLI, Moldex Metric, North, Tasco), DOD (Army, Air Force, and Navy), and DOL, OSHA, and MSHA.

Intermediate Outcomes

Following the 2003 conference, the EPA opened a docket on revising its hearing protector labeling regulation.[10]

EPA Laboratories governed by the Safety, Health and Environmental Management Programs (SHEMP) Operations Manual for Laboratories use hearing protectors meeting the ANSI S12.6 requirements.

OSHA has required a 50% reduction of the NRR for a HPD when estimating the protected exposure level for workers since the early 1990s. The PPT Program's research on HPDs identified an inherent bias for different protector styles. The PPT Program recommends a variable reduction of the NRR that allows for the type of protector: 25% reduction for earmuffs, 50% for foam earplugs, and 70% reduction for all other types of protection.[11] MSHA went further, making no allowance for the attenuation of HPDs for mine workers.[12] OSHA identified subject-fit ANSI S12.6 Method B attenuation data as acceptable, requiring no further reduction factors.[13]

The PPT Program research provided the basis for revisions of national and international testing standards which in turn have affected international regulations for rating and certifying hearing protector performance. The American National Standards Institute rescinded ANSI S3.19 in favor of ANSI S12.6-1984.[13] The PPT inter-laboratory studies contributed significantly to the latest revision ANSI S12.6-1997 (R2002).[14] The revision removed the experimenter-fit protocol and added both an experimenter-supervised and naïve subject-fit protocol. As well, the subject sample size was increased for earplugs and semi-aural insert HPDs. For the justification of the testing protocol, sample sizes and subject-fit testing, the ANSI S12.6-1997[14] standard exclusively cites four PPT Program papers and presentations. [9],[15] As a part of the 5-year

148 maintenance cycle for standards, the ANSI Working Group 11 has commenced revision of the
149 S12.6 standard to incorporate the latest research conducted on protector testing. European
150 standards developed after the EPA regulation are based upon an experienced subject-fit
151 protocol[16] and a less restrictive rating method[17]. The ISO technical committee 43
152 subcommittee 1 for noise standards wrote a test standard based upon the ANSI S12.6 subject-fit
153 protocol.[18] In addition to the subject-fit standard, PPT scientists have contributed substantially
154 to an ISO method to evaluate noise reduction for earmuffs on an acoustic test fixture.[19]
155

156 The ANSI S12.6-1997 standard has been the basis for revisions of several international standards
157 for hearing protector testing and regulations. Australia and New Zealand incorporated subject-fit
158 methods into testing, labeling, and occupational safety and health standards for hearing
159 protectors. The Canadian Standards Association adopted the ANSI S12.6 Method B protector
160 testing and performance classification. Brazil mandated that all hearing protectors sold in Brazil
161 must be tested according to Method B of ANSI S12.6-1997 (R2002)[14] from which the
162 NRR(SF) –subject-fit is calculated for the label.
163

164 PPT efforts to revise the NRR was the motivation for conducting inter-laboratory studies of
165 HPDs in the 1990s and in 2006. The ANSI technical report [20] formed the basis of a new ANSI
166 standard to estimate the effective A-weighted sound pressure level when HPDs are worn. [21]
167 This standard was finalized and will be published in 2007. As an intermediate outcome, this
168 standard is the first ANSI HPD rating standard and has formed the basis of the EPA regulation
169 revision. The standard will affect other countries' regulations as the method gains acceptance
170 within the international community.
171

172 **What's Next?** 173

174 The PPT Program will continue to assist the EPA's regulatory efforts to update its regulations
175 that reflect current HPD testing methods and to develop a noise reduction rating that is more
176 directly applicable to users in occupational settings.[20] The revised regulation will include
177 testing and rating methods for new technologies such as sound restoration, communication,
178 active noise reduction, integrated radio, and level-dependent passive HPDs. The PPT Program
179 has partnered with hearing protection manufacturers, (Aearo/EAR, Bacou-Dalloz and Bose
180 Corporation), the U.S. Army Aeromedical Research Laboratory, U.S. Air Force Wright Patterson
181 Air Force Base, EPA, and various universities to develop recommendations for new
182 technologies, assessment methods, and rating recommendations.
183

Appendix D.1 List of Outputs

Peer Reviewed Publications

Royster JD, Berger EH, Merry CJ, Nixon CW, Franks JR, Behar A, Casali JG, Dixon-Ernst C, Kieper RW, Mozo BT, Ohlin D, Royster LH [1996]. Development of a new standard laboratory protocol for estimating the field attenuation of hearing protection devices. Part I. Research of Working Group 11, Accredited Standards Committee S12, Noise. J Acoust Soc Am 99, 1506–1526.[5]

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Berger EH, Franks JR [1996]. The validity of predicting the field attenuation of hearing protectors from laboratory subject-fit data. J Acoust Soc Am Vol. 100 No 4 Pt 2, 2674.[23]

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Gauger D, Murphy WJ, Berger E, Witt B, Ahroon W, Gerges S [2007]. “Results of an Interlaboratory Study Comparing Method A and B Test Data,” National Hearing Conservation Association Savannah GA Feb 16-17, 2007.[27]

Murphy WJ, Berger EH, Gauger D, Witt B, McKinley R, Gerges, S, Ahroon W. [2006] “Results from the NIOSH/EPA Interlaboratory comparison of ANSI S12.6-1997 Methods A and B.” Acoustical Society of America Meeting Honolulu, Hawaii, Dec. 3-6 [28]

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232 noises based on time-frequency analysis by analytic wavelet transform. Proceedings of Inter-
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236 Performance” proceedings of Inter-noise 2005, Rio de Janeiro, Brazil Aug 7-10.[30]
237
238 Murphy WJ, Byrne DC, Witt B, Duran J [2005].“Psychophysical uncertainty estimates for real
239 ear attenuation at threshold measurements in naïve subjects” proceedings of NOISE-CON 2005,
240 Minneapolis MN Oct 17-19.[31]
241
242 Murphy WJ [2005]. Derivation of an analytic expression for the error associated with the Noise
243 Reduction Rating. Meeting of Acoustical Society of America Vancouver BC, May 2005.[32]
244
245 Murphy WJ [2005]. Current Research Issues for Hearing Protectors. Allied Construction Safety
246 Days Conference, Loveland OH, March 8, 2005 [33]
247
248 Murphy WJ, Shaw PB [2005]. Calculation of the Intrinsic Error in Hearing Protector Ratings.
249 National Hearing Conservation Association, Seattle WA, Feb 21 2005.[34]
250
251 Murphy WJ, Franks JR, Shaw PB [2004]. Estimating the Precision in Hearing Protectors Ratings
252 Acoustical Society of America / New York, NY. May 2004.[35]
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273 105 No. 2, Pt. 2,1131.[42]
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281 Conservation Association, February 19-21, Albuquerque, NM.[44]
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283 Murphy WJ, Franks JR, Hall SJ, Krieg EF [1997]. Differences between binaural sound-field
284 thresholds and monaural audiometric thresholds. J Acoust Soc Am Vol. 101, No 5, Pt. 2,
285 3126.[45]
286

D.2 Develop Hearing Protection Laboratory and Fit-Testing Methods. (Strategic Goal 3, Objective 3)

Issue

Although NIOSH scientists invented and evaluated the first HPD fit-testing systems in the late 1970s, [46, 47] commercial fit-testing systems were not available until the development of portable computers with high-quality sound capabilities in the late 1990s.[48] Like respirators, HPDs must fit properly or they won't protect the wearer. There is a need to transfer HPD ratings to effective hearing protection for an individual worker on the job. Better test standards and more predictive ratings provide useful population statistics, but are not applicable to the individual worker. The PPT Program identified that fit-testing needs to be performed in conditions with elevated background noise levels and must be able to predict attenuation from limited data.

Approach

The PPT Program pursued a coordinated effort to develop laboratory testing capabilities and evaluate potential fit-testing and rating methods. Also, estimates of the noise attenuation from HPDs in the workplace were developed, as well as validating the new laboratory subject-fit protocol[14] with onsite field-testing methods.[49] In a recent longitudinal study, 90% of workers who were fit-tested achieved protected noise exposures below 85 dB(A).[50]

In 2000, PPT Program scientists met with the senior audiologist of Howard Leight Industries (HLI) responsible for HPD development and testing to specify the requirements for a new laboratory testing system based on commercially available signal generation hardware. This partnership resulted in a laboratory system (HPDLab) suitable for both ANSI and ISO testing of Real-Ear Attenuation at Threshold (REAT).[51] HPDLab testing system uses commercially available signal generation equipment, audio amplifiers, and speakers controlled through software developed by the PPT Program. HPDLab software program incorporated multiple psychoacoustic methods to measure attenuation. The PPT Program developed analyses to estimate protected exposure levels from limited data [52, 53] and to statistically classify the quality of a user's fit based upon the attenuations. [54] The PPT Program studied the performance of proposed fit-testing systems and demonstrated the equivalence of attenuation estimates between ANSI S12.6-1997 Method B and a computer-based fit-test system.[55]

The PPT Program-developed, laboratory-based HPD testing system has lowered the cost of developing new hearing protector testing laboratories. Exclusive of the cost of the reverberant acoustic testing chamber, the HPDLab system can be installed for about \$15,000. A comparable commercial system would cost \$80,000 or more and would still require many hours of customization work. The HPDLab has been installed in Cincinnati and Pittsburgh as well as the Howard Leight Industries testing laboratory in San Diego.

Output and Transfer Highlights

The HPDLab software and fit-testing research have been the topic of more than 20 presentations at national and international conferences. HPDLab was developed as a tool for the PPT Program

to research testing methods and as a product for commercial testing laboratories with a lowered entry cost. The results of the comparison of field testing methods were published in the American Industrial Hygiene Association Journal. The PPT Program has worked closely with hearing protector industry manufacturers who review NIOSH research findings and proposals.

Intermediate Outcomes

U.S. Army Aeromedical Research Laboratory has installed the NIOSH HPD Lab system for testing hearing protection technologies to develop and test crew communication systems for armored and airborne cavalry units.

Both PRL and HLI laboratory have achieved National Voluntary Laboratory Accreditation Program (NVLAP) for ANSI S12.6-1997.[14] HLI performs in-house testing of its products and has recently completed its portion of the NIOSH-sponsored interlaboratory study with the HPDLab software.

PRL and Cincinnati are developing a multisubject fit-testing system using the HPDLab software code as a basis. These systems will be made available to interested parties to provide mobile fit-testing capabilities.

The PPT Program is working with NASA to develop the third generation of the HPDLab system to make it accessible to a larger base of users and updating the hardware to function on a National Instruments platform using signal generation technology that was previously unavailable in 2001.

External Factors

Gentex Corporation has adopted the NIOSH HPD Lab system, but hasn't been able to devote resources toward installing it.

What's Next?

The PPT Program has contracted with the University of Cincinnati to develop a multi-station fit-testing system that will integrate audiometry and fit-testing into a single testing system built from commercially available signal generation hardware. Once completed, HPDFit will be installed for field testing in mobile testing units such as the PPT Program's mobile audiometric research facility operated out of PRL and in fixed testing facilities such as those found in industry and the military. The PPT Program continues to test the doseBusters USA Exposure Smart Protector (ESP) integrated dosimeter and hearing protection system. Reported doses measured in the occluded position less than 85 dB(A) indicated adequate hearing protection. The ESP represents a novel use of existing technology to monitor the fit of an HPD through continuous sampling of the noise exposure based upon how the protector is worn.

Appendix D.2 List of Outputs

Peer Reviewed Publications

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D.3 Evaluate the Effectiveness of Hearing Protection Devices to Provide Protection From Impulsive Noise. (Strategic Goal 3, Objective 4)

Issue

More than 1.8 million U.S. workers are exposed to potentially hazardous levels of impulsive noise. This estimate includes federal, state, and local law enforcement officers, DOD infantry, armor, and artillery personnel, and workers in the construction and mining sectors.[65] In addition, 50% of U.S. industrial workers are believed to be exposed to impulsive noise due to recreational use of firearms in activities such as target shooting or hunting.[66]

High-intensity impulsive sounds are considered to be more damaging to hearing than continuous sounds. Exposure to impulsive sound can cause acute acoustical trauma, which can be followed by symptoms such as tinnitus and temporary hearing impairment. Sudden hearing loss may also occur from exposure to impulsive sounds that exceed a critical sound pressure level by causing direct mechanical damage to the middle and inner ear. [67]

The potential hazard of exposing human test subjects to high impulse levels combined with the lack of sufficiently isolated acoustic test fixtures has limited research in developing hearing protection devices for use in impulsive noise. The EPA labeling regulation states: "Although hearing protectors can be recommended for protection against the harmful effects of impulsive noise, the NRR is based on the attenuation of continuous noise and may not be an accurate indicator of the protection attainable against impulsive noise such as gunfire." [1] Accordingly, OSHA established a non-enforceable level to a permissible exposure level (PEL) of 140 dB [68] and MSHA has established a PEL of 115 dB(A). [12] To date they are non-enforceable because national guidelines and standardized methods are not available for evaluating the performance of HPDs in attenuating impulsive sounds. However, PPT Program researchers have addressed the need for updated guidance and regulations related to impulsive noise. [69] [22]

Approach

Collaboration with University of Cincinnati applied new analytic metrics to the evaluation of impulse responses for hearing protection devices. Hearing protector attenuation is most often evaluated through real ear attenuation at threshold (REAT) measurements, but can be assessed with a microphone in real ear or using an acoustic test fixture. The PPT Program constructed an acoustic shock tube to generate impulses necessary to measure the level dependent transmission loss of HPDs while mounted on an acoustic test fixture.

The PPT Program is also involved with ANSI and ISO development of testing standards for measuring the performance of HPDs in impulsive environments. In 2001 and 2002, the PPT Program staff evaluated the effectiveness of more than 20 hearing protectors at indoor and outdoor firing ranges with impulses generated by small-caliber weapons and peak impulse levels ranging from 140 to 170 dB sound pressure level (SPL). [69, 70]

The PPT Program is leading efforts to establish national and international standards on characterizing the effectiveness of hearing protection devices against impulsive noise. PPT

Program scientists frequently serve on standards-setting committees providing expertise and an opportunity to disseminate PPT Program research findings and recommendations.

In 2000, PPT researchers initiated a new effort to collect data published by manufacturers of hearing protectors sold in the United States to augment or replace the data collected for the 1994 Hearing Protector Compendium. The electronic version contains updated information on the use of the REAT attenuation values and standard deviations for the purpose of calculating the attenuation. It's available at the following web site:
<http://www.cdc.gov/niosh/topics/noise/hpcomp.html>.

Output and Transfer Highlights

Research efforts on hearing protection devices and their effectiveness against impulsive noise have been presented at national and international professional conferences and in three peer-reviewed journals.[53, 71, 72] Also, PPT Program scientists published an Alert document on hazardous noise at indoor firing ranges in 2007.

PPT Program provided the only external input to the DoD's proposed rule for a design limit criteria for exposure to impulsive noise, MIL STD 1474E .

The PPT Program and the NHCA co-sponsored a Best Practices Workshop on Impulsive Noise and Its Effects on Hearing in 2003. A peer-reviewed publication on the summary and findings from this workshop was published in the Noise Control Engineering Journal.[73]

In November 2005, the PPT Program published a NIOSH Health and Safety website for Indoor Firing Ranges that includes information on NIOSH Health Hazard Evaluations (HHEs), technical documents, publications, and recommendations on reducing exposure to impulsive noise at indoor and outdoor firing ranges. [74]

PPT Program scientists analyzed the impulses using several damage risk criteria and recommended the use of double hearing protection whenever impulses exceed 140 dB SPL. Also, a combination of an electronic level-limiting earmuff and a passive earplug was recommended to improve the communication when using dual protection.

PPT Program scientists published two HHE reports for the Fort Collins Police Service[69] and for the Immigration and Naturalization Service, National Firearms Unit [70]. The reports provided recommendations on the selection and use of appropriate hearing protection devices to limit exposure of law enforcement officers to harmful impulsive sound levels.

A compendium of hearing protectors was published in 1976, followed by successive updates of that information in 1985, 1995, and 2003. PPT Program updated its Electronic HPD Compendium to include information about attenuation of hearing protection devices against impulsive noise.

Intermediate Outcomes

The Department of Homeland Security, U.S. Citizenship and Immigration Service has disseminated PPT Program recommendations on appropriate use and selection of hearing protection devices among all National Firearms Units that are responsible for training more than 19,000 officers, the largest nonmilitary armed force in the federal government.

Major hearing protector manufacturers in the United States report using the NIOSH web-based compendium. For example, in the past year, Bacou-Dalloz reported using the compendium in presentations to more than 200 hearing protector distributors and safety professionals. The organization includes reference to the compendium in its training presentations and refer incoming callers to it through the technical support section.

A Google search on NIOSH Hearing Protector Device Compendium revealed 27 direct links from other sites to the compendium. These links include three union or worker organizations, five university hearing conservation or industrial hygiene programs, six hearing health-related manufacturers, two audiology service providers, six safety organizations, two government entities, and three resellers of hearing protectors.

The Department of Energy (DOE), Oak Ridge National Laboratory is implementing PPT Program HPD recommendations for DOE law enforcement personnel.

OSHA established a non-enforceable level to a permissible exposure level (PEL) of 140 dB and MSHA has established a PEL of 115 dB(A) for impulsive noise, based on PPT Program efforts.

Spurred by the availability and wide use of the compendium, two major manufacturers to date have voluntarily supplied subject-fit data for their products. Although not currently required by the EPA for all hearing protectors, subject-fit data most accurately represent real world hearing protector attenuation. The NIOSH 1998 Criteria Document recommended using subject-fit data because they would eliminate the need to use controversial de-rating schemes.

What's Next?

The PPT Program is involved in dissemination activities resulting from its impulsive noise research. A NIOSH Workplace Solutions document is being written with simple and specific recommendations for preventing and reducing noise-related hazards in the workplace. The PPT Program is developing a new version of the HPD compendium with more efficient methods for search strategies to identify appropriate protection. Also, the PPT Program is developing training materials for proper selection and fitting hearing protection devices for use in impulsive noise environments.

Appendix D.3 List of Outputs

Peer Reviewed Publications

Kardous, CA, Willson, RD, Hayden, CS, Szlapa, P, Murphy, WJ, and Reeves, ER, [2003]. Noise exposure assessment and abatement strategies at an indoor firing range. Appl. Occup. Env. Hyg. 18, 629-636.[75]

Kardous CA, Willson RD, Murphy WJ [2005]. – Noise dosimeter for monitoring exposure to impulse noise. Applied Acoustics Journal, 66 (2005) 974-985.[76]

Publications

Kardous CA [2007]. NIOSH Alert occupational hazards for indoor firing ranges, DHHS-CDC-NIOSH, (2007) In press.[77]

Tubbs, RL, Murphy, WJ. [2003]. NIOSH Health Hazard Evaluation Report: HETA #2002-0131-2898 Fort Collins Police Services, Fort Collins, Colorado. DHHS-CDC-NIOSH, March [2003].[69]

Book/Chapters/Proceedings/Abstracts

Murphy WJ [2003]. Deriving a new NRR from ANSI S12.6B method, inter-laboratory reproducibility of data and precision of the data. U.S. Environmental Protection Agency Workshop on Hearing Protector Devices, Washington DC, March 27 – 28.[78]

Franks JR, Harris DA, Johnson JL, Murphy WJ [1999]. Alternative field methods of measuring hearing protector performance. Abstracts of the Midwinter Meeting of the Association for Research in Otolaryngology.[61]

Conferences and Presentations

Murphy WJ, Zhu X-D and Kim J [2006]. Study of the effect of hearing protectors for military noises based on time-frequency analysis by analytic wavelet transform. Proceedings of Inter-Noise 2006, Honolulu, Hawaii, Dec 3-6, 2006.[29]

Kardous CA, Murphy WJ [2005]. New System for monitoring exposure to impulsive noise, proceedings of Inter-noise 2005, Rio de Janeiro, Brazil Aug 7-10, 2005.[79]

Murphy WJ, Kardous CA, Byrne DC, Zechmann EL[2007]. Auditory risk of hearing loss due to gunshot noise exposure, National Hearing Conservation Association Savannah GA Feb 16-17, 2007.[80]

Kardous CA and Murphy WJ [2007]. Noise abatement for indoor firing ranges, USPHS Professional Conference, Cincinnati OH June 4-7, 2007.[81]

- 631 Murphy WJ [2006]. Evaluation of level-dependent hearing protection devices for use with
632 impulse noises. American Industrial Hygiene Conference & Expo (AIHce), May 13-18 in
633 Chicago, Illinois.[82]
634
- 635 Murphy WJ, Franks JR, Behar A. [2004]. Hearing protector labeling for active noise reduction
636 devices. Acoustical Society of America San Diego CA, November 18.[83]
637
- 638 Murphy WJ. [2004]. Evaluation of level-dependent hearing protection devices for use with
639 impulsive noises. American Industrial Hygiene Conference 2004 Noise Symposium, Atlanta GA,
640 May 9.[84]
641
- 642 Murphy WJ. [2004]. Evaluation of level-dependent hearing protection devices for use with
643 impulsive noises. National Hearing Conservation Association, Seattle WA, Feb 21.[85]
644
- 645 Murphy WJ. [2003]. Peak reductions of nonlinear hearing protection devices. National Hearing
646 Conservation Association/NIOSH Best Practices Workshop on Impulse Noise, Cincinnati, OH
647 April 7-8.[86]
648
- 649 Murphy WJ, Kardous CA. [2003]. Attenuation measurements of linear and nonlinear hearing
650 protectors for impulse noise. J. Acoust. Soc. Am., Vol. 113 No. 4 Pt.2, 2195.[87]
651
- 652 Kardous CA, Murphy WJ, Willson RD. [2003]. Personal noise exposure assessment from small
653 firearms. J. Acoust. Soc. Am., Vol. 113 No. 4 Pt.2, 2195.[88]
654
- 655 Franks JR, Murphy WJ. [2002]. Do sound restoration hearing protectors provide adequate
656 attenuation for gunfire noise. J. Acoust. Soc. Am., Vol. 112 No. 5 Pt. 2, 2294.[89]
657
- 658 Murphy WJ, Little MB. [2002]. Performance of electroacoustic hearing protectors. J. Acoust.
659 Soc. Am., Vol. 111 Pt. 5, 2336[90]
660

D.4 Develop an Integrated Hearing Protection And Communication System. (Strategic Goal 3, Objective 5)

Issue

Hearing protection devices present a challenge for communication in noisy environments. In certain work settings such as firefighting and emergency response, engineering noise controls are difficult, if not impossible, to implement. Workers must instead rely on personal hearing protection, such as standard earplugs, to prevent noise-induced hearing loss. Conversely, worker safety depends on the ability to hear and understand the speech of other workers, plus one's own speech, particularly in a noisy setting. Given the choice between personal safety and hearing loss prevention, workers opt not to wear HPDs because they think that HPDs impair communications. [91] A survey of health and safety professionals found that 65% of those responding thought the workplace would be safer if workers could easily communicate with each other and with supervisors.[92]

Approach

PPT Program researchers developed and built several customized applications of the EarTalk system for trials in auto racing, firefighting, and the military. In 2002, a prototype EarTalk system was tested in high-noise environments at the Voice Communication and Research Evaluation System facility at Wright-Patterson Air Force Base. The tests showed that EarTalk performed as well as current racing communication systems but did not achieve the same level of speech intelligibility as more expensive military communication headsets with noise canceling microphones underneath a noise-reducing muzzle.

Output and Transfer Highlights

EarTalk is a communication device that is incorporated into a HPD that was developed by PPT Program researchers between 1989 and 1991. EarTalk provides workers with the means to communicate clearly with speech while protecting their hearing. The EarTalk device uses a miniature microphone to detect the speech signal in the ear canal of the talker, electronically processes the sound to restore natural sound quality and transmits the signal to miniature speakers in the ear canal for a listener. [93]

Research information has been presented and demonstrated at national and international conferences and expositions.

Four publications and a book chapter have resulted from this research.

Intermediate Outcomes

PPT Program researchers were awarded a U.S. Patent for the EarTalk system in 1991.

EarTalk technology is available for licensing through CDC technology transfer office. To date, one licensee (Cavcom, Inc.) has incorporated EarTalk into a system that works with Motorola

706 radios commonly used by police and firefighters. Cavcom, Inc. has marketed a modified EarTalk
707 system for more than 2 years.

708
709 **What's Next?**

710
711 EarTalk remains as a viable alternative to existing and mostly outdated communication systems,
712 but due to lack of funding and challenges associated with technology transfer of publicly-
713 developed inventions to the private sector, the system's potential has yet to be fully recognized.
714 The CDC and NIOSH technology transfer offices are helping to formulate a new marketing
715 strategy.

Appendix D.4 List of Outputs

Publications

Gwin K, Wallingford K, Morata TC, Van Campen LE [2001]. Hazard evaluation and technical assistance report: Human Performance International, Inc., Charlotte, North Carolina. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH Report No. HETA 00-0110-2849.[94]

Stephenson MR, Merry CJ. Hearing Protection for Miners. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-151.[95]

Peer Reviewed Publications

Kardous CA [2003]. EarTalk: Protector and microphone. The Military Engineer, No. 621, 43 44.[96]

Morata TC, Fiorini AC, Fischer FM, Krieg EF, Gozzoli L, Colacioppo S [2001]. Factors affecting the use of hearing protectors in a population of printing workers. Noise and Health 4(13): 25 32.[97]

Book/Chapters/Proceedings/Abstracts

Kardous CA [1998]. Eartalk - Hearing Protector and Communication System in Prasher P., Luxon L., Pykko I. (eds.), Advances in Noise Research, Volume II: Protection Against Noise. John Wiley.[93]

Conferences and Presentations

Kardous CA [1997]. EARTALK - Hearing Protector and Communication System. Paper and poster presentation at the Second Pan European Conference on Protection against Noise, London, England, June 16-19, 1997.[98]

Patents

Franks J.R., Dunn D.E., Sizemore C.W. [1995]. Ear Based Hearing Protector/Communication System. U.S. Patent # 5,426,719. U.S. Patent and Trademark Office, Washington, D.C.[99]

D.5 Develop Hearing Protection Recommendations for Noise-Exposed Hearing-Impaired Workers. (Strategic Goal 3, Objective 6)

Issue

Of the 19 million U.S. adults estimated to have hearing impairments, nearly half are currently employed.[100] Nine of 10 coal miners, four of seven carpenters, and one of three automobile production workers with at least 20 years of employment have material hearing impairment due to noise exposure.[101-106] Many hearing losses are incurred during the first 5 to 10 years of employment.[107, 108] Workers frequently spend the rest of their careers trying to function in a noisy environment impaired by a hearing deficit.

Hearing impaired workers face a dilemma of needing to protect their residual hearing and also needing to communicate[109-111] and identify environmental cues and warning signals [112] [113, 114] without additional “impairment” imposed by use of conventional HPDs. However, HPD selection is based upon the worker’s noise exposure and HPD attenuation characteristics without consideration of hearing impairment.

Noise-exposed, hearing-impaired workers face special problems. Conventional hearing protectors typically improve speech intelligibility for normal-hearing persons; however, hearing protectors degrade speech intelligibility for hearing-impaired listeners.[109-111],[115] Hearing protection also diminishes the ability of hearing-impaired workers to perceive certain warning signals [112, 113] and monitor sounds in the work environment (e.g., equipment noises). Hearing-impaired workers have also been shown have an increased risk of occupational injuries.[114]

Current hearing conservation regulations do not distinguish between workers who have normal hearing and those who have hearing loss. Although the Americans with Disabilities Act of 1990 requires employers to make reasonable accommodation for handicapped workers, it provides no guidelines for managing hearing-impaired workers except those who are completely deaf. No government or professional organization has published guidelines or policies concerning the management of noise-exposed, hearing-impaired workers; therefore hearing conservation professionals do not have the information necessary to make appropriate recommendations to accommodate these individuals.

In the 1988 Proposed National Strategy for the Prevention of Noise-Induced Hearing Loss (NIHL), NIOSH noted that “the job-related consequences of occupational NIHL may threaten a worker’s employment status.” [116] Rehabilitation and accommodation strategies for noise-exposed, hearing-impaired workers were identified as research needs in the 1998 revision of the noise criteria document. [49]

Approach

In 2002, the PPT Program conducted a series of focus groups and in-depth interviews with noise-exposed hearing-impaired workers, their supervisors, and managers of hearing conservation programs. The objective was to obtain their perspective on the effect that hearing loss and noise

exposure have on safety, communication, and job performance; difficulties encountered; information needed to effectively accommodate these workers; and knowledge of currently-available options. Workers, supervisors, and hearing conservation managers reported that working in noise with a hearing loss does not have much of an effect on worker productivity, but does present a concern for employee safety, particularly regarding communication and the ability to hear important environmental sounds.

Particular jobs require that a worker be able to hear warning sounds and to communicate with other workers. PPT Program scientists are working on methods to establish consistent guidelines for determining the minimum auditory requirements for a job or task. These guidelines will ensure that the safety of the workers is not compromised by hearing impairment. Furthermore, the guidelines will be targeted to prevent workplace discrimination for those hearing-impaired workers when they can be accommodated or when hearing is not critical to performance, productivity, or safety.

Beginning in 2001, PPT Program scientists evaluated alternative hearing protection options, such as flat-attenuation HPDs and the use of hearing aids under earmuffs, to determine their utility in alleviating the special problems faced by hearing-impaired workers. An assessment/intervention protocol for hearing-impaired HPD users was developed from this work and tested in the PPT Program's audiological laboratory. NIOSH, General Motors, and the UAW field-tested the protocol with a group of hearing-impaired, noise-exposed manufacturing employees in Michigan. From this research PPT Program scientists are developing a protocol for selecting the HPDs that will maximize speech intelligibility for a hearing-impaired worker while still providing sufficient reduction in noise exposure. Hearing impaired workers have been recruited and audiometric assessment and speech intelligibility testing are currently in process.

Output and Transfer Highlights

Laboratory research on the effects of earmuff attenuation characteristics on speech intelligibility for hearing impaired subjects was the topic of a Ph.D. dissertation at The Ohio State University of one former HLR staff member. [117] A project protocol has been approved to field-test the models developed from the laboratory findings with hearing-impaired workers in the manufacturing sector. [118, 119]

Research has indicated that warning signals need to be lower in frequency in order to be perceived by workers with hearing loss. In some situations, visual alerting devices may be required, although focus group participants reported that visual signals are not always appropriately placed to be useful.

PPT Program results of this effort are already providing OSHA, MSHA, employers, and professional organizations with needed guidance on managing hearing-impaired individuals who work in noise through consultation and presentations.

What's Next?

847 Upon completion of the field evaluation, a computer spreadsheet model to estimate the exposure
848 of hearing-impaired workers will be made available as a tool that professionals can use when
849 developing recommendations to accommodate noise-exposed, hearing-impaired workers.

850
851 Research will be conducted on how to train workers to maximize residual hearing (listening
852 strategies, lip-reading, optimal use of hearing aids, alternative communication methods). This
853 research need was identified in the 1998 criteria document. It was also recommended as a result
854 of the focus group study, based on comments from participants indicating the extent of their
855 reliance on non-verbal communication techniques. Because these techniques must be learned,
856 new hearing-impaired workers in particular may be at a disadvantage and possibly at increased
857 risk for accidents.

858
859 Additional accommodations for hearing-impaired, noise-exposed workers (e.g., alternative
860 warning systems) will be developed and evaluated to recommend a protocol for determining
861 when a particular worker needs such accommodations. Practical recommendations for the
862 accommodation of noise-exposed, hearing-impaired workers will be published as a NIOSH
863 “practical guide” oriented towards the special needs of noise-exposed, hearing-impaired workers.

864
865 The research findings in this program will provide input to the ANSI subcommittee on
866 bioacoustics (S3) or noise (S12) to develop a method of predicting the ability of an individual to
867 communicate in noise while wearing hearing protection.

Appendix D.5 List of Outputs

Peer Reviewed Publications

Morata TC, Themann CL, Randolph RF, Verbsky BL, Byrne DC, Reeves ER [2006]. Attitudes and beliefs about hearing loss prevention among workers with self-reported hearing difficulties. *Ear & Hearing* (in press).[120]

Book/Chapters/Proceedings/Abstracts

Verbsky BL [2002]. Effects of conventional passive earmuffs, uniformly attenuating passive earmuffs, and hearing aids on speech intelligibility in noise. Doctoral dissertation, The Ohio State University.[117]

Conferences and Presentations

Randolph R [2004]. Working Impaired in Dangerous Settings: What the Workers Tell Us. Platform presentation at the National Hearing Conservation Association annual conference.[121]

Verbsky BL [2004]. Accommodation of hearing-impaired workers in noise. Research podium presentation, Annual Convention of the American Academy of Audiology.[122]

Verbsky BL [2003]. Hearing aids + earmuffs: Safe & effective within limits. Poster presented at the National Hearing Conservation Association annual conference.[123]

Verbsky BL, Feth LL [2002]. Hearing conservation: Hearing protection versus speech intelligibility and personal safety. Poster presentation at the 2002 meeting of the American Auditory Society.[124]

D.6 Develop and Improve Fall Arrest Harnesses. (Strategic Goal 3, Objective 7)**Issue**

Falls are second only to motor-vehicle crashes as a leading cause of death and injury in the workplace. Falls cause 313,000 disabling injuries to American workers, and more than 700 deaths each year. Falls from elevation are a special concern. On average, 651 American workers die and nearly 86,900 suffer injuries each year as a result of falls from elevation. [125] The cost of a single fall-from-elevation injury usually starts at around \$500,000 and easily reaches \$1 million or more when third-party suits are involved in severe injury cases.

The construction industry has the highest frequency of fall-from-elevation incidents, followed by the wholesale and retail trade, service, and transportation industries. Most often, construction workers fall from roofs, ladders, and scaffolds. OSHA regulations require that fall-arrest harnesses, guardrails, or safety nets be used as protective measures for tasks that are performed above 6 feet of height. In some cases, engineering controls such as guardrails or safety nets are inadequate or impractical, and are therefore not implemented. In these cases, if the work cannot be redesigned to prevent or reduce fall-from-elevation hazards, personal protective equipment is often used. One type of PPE that is widely used during various construction phases is the fall-arrest harness.[126]

Fall-arrest harnesses provide the last line of defense for the 10.8 million construction workers in areas where fall hazards cannot be completely eliminated. Full-body harnesses, which replaced waist belts and chest-waist harnesses more than 10 years ago, are considered the standard body support components of personal fall-arrest systems in the United States and Canada. [127] Despite the important role played by harnesses as protective devices in construction and general industry, there are problems associated with them that can impact whether or not they are used at all, and if they are used, whether they are safe.

First, fall-arrest harnesses must be properly fitted and sized for individual workers. The Anthropometric (human body measurement) data used in current harness designs are based on studies with military personnel conducted in the 1970s and 1980s, and do not represent the current general U.S. worker population. Also, workforce demographics have changed, with more women and minorities employed in occupations that use harnesses. Resulting changes in the anthropometric characteristics of workers using harnesses mean that current sizing data may be inadequate and potentially dangerous.

Second, workers wearing harnesses who fall and are suspended in the harnesses may be at risk of "Suspension Trauma." Research has shown that subjects experience respiratory distress within 5 to 30 minutes of suspension in a full-body harness. Information is lacking on how full-body fall harnesses fit workers when they are suspended after a fall.[128] Updated information on human tolerance in suspended postures and on solutions to minimize suspension trauma is needed.

Little has been published on either proper fit and sizing of harnesses, or the risks and exposures associated with workers being suspended after falls arrested by harnesses. These current limitations in harness design can result in non-use of harnesses, improper size selection, failure

to don harnesses properly, and poor harness-user interfaces, each of which may result in increased risk. Advanced technology and methods available through the NIOSH PPT Program provide unique capabilities for developing sizing schemes and redesigning harnesses to provide safe, user-friendly, and ergonomically appropriate designs.

Improvements in fall-arrest-harness sizing and design could reduce the risk of worker injury.

Another distinct PPT research effort is examining potential improvements in footwear designs that might reduce risks of 1) fall-from-elevation-related injuries and fatalities for workers on roofs and other elevated work areas, and 2) slip, trip and fall (to the same level) risks for healthcare and other service workers.

Approach

The overall goals of the research effort focused upon fall-arrest harnesses are

1) The establishment of anthropometric guidelines for the design of improved full-body harnesses

2) The development of effective harness-sizing systems that will better accommodate the current population of U.S. workers, and

3) The reduction of physiologic stresses experienced by workers suspended in fall-arrest harnesses after a fall.

The PPT Program used an advanced scanning technology to perform rapid (17-second) whole-body 3D scans of workers in both standing and suspended conditions. Tests with traditional, time-intensive anthropometric tools and methods are unacceptable for testing human subjects suspended in harnesses, since respiratory distress can occur in as little as 5 minutes.

The PPT Program then evaluated the range of body shapes accommodated by current sizing schemes and tested current static fit criteria for their usefulness in determining how well harnesses fit after a fall. Findings from these studies of workers in the construction trades showed that 24% to 40% of participants failed fit criteria for two types of harnesses, confirming the need for more accurate data on the interface between the human body and safety harnesses.

Mathematical parameters were established to determine the points of contact between the human body in its various shapes and the safety harness, and to define optimal sizing schemes. Thigh strap angle and harness back D-ring location were identified as additional critical static-fit-test criteria to predict post-fall harness fit. The power of these studies was increased through the addition of data from an international anthropometric database of 2,340 subjects, known as CAESAR (Civilian American and European Surface Anthropometry Resource). CAESAR was developed through use of a similar 3D scanning procedure by a consortium of industrial and government agencies.

Along with two harness manufacturers, the PPT Program team has applied the mathematical parameters developed through the PPT pilot studies to the CAESAR database to establish the adjustment range of each harness component. This is an important step to enable transfer of the scientific research results into industrial design practice. The PPT Program is one of the few

international programs with the ability to perform 3D digitization research and human-harness-interface modeling for harness design applications.

Further, PPT Program scientists conducted experiments to determine the amount of time persons can withstand suspension in properly-sized harnesses, as well as a human physiology study to determine effectiveness of an intervention to reduce physiologic stress to workers suspended in harnesses. The intervention was a harness accessory invented by PPT researchers. After a fall, this accessory automatically supports a wearer in a sitting position with the knees elevated at a position at or above the hips. It was found to increase suspension times for subjects. Mean suspension time was measured at 58 minutes (range 39 to 60 min) for the tests with the harness accessory, but only 29 minutes (range 5 to 56 minutes) for tests without the accessory. Two major harness manufacturers (Mine Safety Appliances Co. and DBI-SALA Fall Protection Inc.) have actively participated in this research and are working with the PPT research team to finalize the adjustment range of each harness component. These manufacturers have provided original static-test criteria, harness blueprints, and technical input for each study, and have continued to provide feedback on proposed new sizing systems. They also are developing harness prototypes based on the proposed sizing systems and other NIOSH Program study results reported above.

The principal goals of the research effort examining shoes are

- 1) The development of improved designs for footwear used in work on roofs and other elevated surfaces, including sensory-enhancing technology that can improve worker balance, and
- 2) The development and evaluation of new sole designs to reduce risk of slips, trips, and falls to the same level among service workers.

PPT researchers developed a surround-screen virtual reality (SSVR) system, the first SSVR system in the world designed for occupational fall prevention research. Validation studies have confirmed that the SSVR system is a valid tool for fall-from-roof prevention research. The system is currently used to evaluate human performance at elevation, identify risk factors leading to fall incidents, and assess new fall prevention strategies and technologies. One effort using the SSVR system addressed how improvements in footwear could reduce injuries and fatalities from falls. In addition to findings that identify footwear design features that improve worker stability and balance, sensory-enhancing technology has been used in the engineering of “smart” shoe inserts to improve workers' balance on roofs. A prototype “smart” shoe with random vibration insert has been constructed. The ability of this technology to reduce the risk of falling has been demonstrated in SSVR laboratory tests. Improved footwear designs for work on roofs have been developed based upon this research effort.

Program researchers are also addressing slip, trip, and fall hazards faced by healthcare and other services workers, among whom injuries from falls to the same level often occur. New footwear sole designs were developed based on analysis of 6 years' data on slip, trip, and fall injuries among hospital workers. Researchers identified surfaces that presented the greatest risk of slip and trip-related injuries for healthcare workers. PPT researchers also conducted finite element modeling of the knee as part of its ongoing research into identifying slip, trip and fall hazards, and developed a training module for maintaining “healthy knees.”

Output and Transfer Highlights

The research report on current harness-sizing issues and the effect of thigh strap angle and back D-ring location as additional harness static-fit-test criteria to enhance post-fall harness fit was published in the journal *Ergonomics* in 2003. The research received the prestigious International Ergonomics Association (IEA) Liberty Mutual Prize in Occupational Safety and Ergonomics in 2002. The information in the article can help construction employers and workers select the right size and proper donning of harnesses.

Findings from the human physiology study regarding the use of intervention technology to reduce the potential of suspension trauma were presented at the American Industrial Hygiene Conference and Exposition in 2006.

A provisional patent application was filed on July 14, 2006 for this intervention technology—a harness accessory that automatically supports a wearer in a sitting position with the knees elevated at a position at or above the hips after a fall (CDC Ref. No. I-002-06). The information, along with the harnessing research results, will be shared with harness manufacturers for the new generation harness design.

A provisional sizing scheme with an algorithm that describes the human torso shape-and-size distribution and a set of recommendations for producing vest-type harnesses has been accepted for publication by the Human Factors journal. A simplified version of the provisional sizing schedule was presented at the Ergonomics Society Conference and published in *Contemporary Ergonomics* in 2005. The draft report of a second provisional sizing scheme has also been shared with MSA and DBI-SALA.

Results from the study of suspension trauma, which provided data on the amount of time persons can withstand suspension in properly-sized harnesses, were disseminated to standards-setting organizations, such as the International Society for Fall Protection (ISFP) and American Society of Safety Engineers (ASSE).

PPT researchers reported on the use of virtual reality in studying falls from elevation at the National Occupational Injury Research Symposium in 2000, and at the Human Factors and Ergonomics Society 46th Annual Meeting in 2002. Staff members from the Finnish Institute of Health and the Japan Occupational Health University have expressed interest in adopting the SSVR concept as a foundation for developing their fall prevention research laboratories. NIOSH researchers have used the technology to identify human fall mechanisms and evaluate engineering concepts for fall-from-roof prevention.

The PPT Program used virtual reality technology to evaluate the effects of different styles of footwear on workers' instability at elevation and has reported results to the safety scientific community. Workers' balance on elevated and narrow surfaces was significantly improved with footwear styles that had high uppers and provided good motion control. Proper shoe selection and improved design of specialized work footwear would enhance workers' stability at height. An article detailing these findings was submitted to the journal *Ergonomics* in 2006.

In collaboration with researchers from Boston University, construction program researchers built and tested a prototype randomly vibrating ("smart") shoe insert to improve workers' balance at

elevation. The smart-shoe insert increases the pressure-sensitivity under the feet by inducing below-sensory-threshold mechanical vibrations.

Additional outputs included a report on the analysis of slip, trip, and fall injury data of hospital workers; a finite element model of the knee; and a training module for maintaining “healthy knees.”

All efforts under this sub goal area are at the stage of transferring knowledge and technologies developed through research to research organizations and private-sector companies for further development and commercialization. The processes of transfer and commercialization can proceed for years before products are realized, marketed, and implemented in workplaces to reduce risk, thereby reducing injuries and fatalities. Although there are no end outcomes to report, there are promising intermediate steps to report.

Intermediate Outcomes

Mine Safety Appliances Co. (MSA) and DBI-SALA Fall Protection Inc. are currently developing prototype harnesses that incorporate the PPT sizing scheme. MSA also has indicated interest in more extensive efforts to develop next-generation harness designs and prototypes using the criteria and schemes identified by the PPT Program. MSA was strategically selected to participate in the PPT pilot studies in 2000 because company officials had previously expressed interest in revising fall protection designs using updated human form measurements. Both MSA and DBI-SALA also responded to a NIOSH announcement in the Federal Business Opportunities in 2003 for partnership in harness-sizing studies and in transferring the knowledge to design and commercialization. Since the two manufacturers account for about 60% of the national market share of fall-arrest harnesses, the future adoption potential of the new harnesses and sizing systems in the construction trades is very high

External Factors

In the United States, worker training on regulations (i.e., use of guardrails, safety nets, or fall-arrest systems) has for decades been the primary focus for preventing falls. However, many construction activities have been exempted from the regulatory requirements for practical reasons (i.e., technology, cost, and operation). In addition, research aimed at preventing falls has been hindered because of the difficulty in accessing work environments and worker activities at elevation (even with management and workforce cooperation), the dynamic nature in the construction industry, and the potential injury risk to researchers. Also, testing new engineering solutions at elevated construction sites can expose workers to additional fall exposures and risks. Consequently, the fatalities and injuries associated with falls from elevation have remained high for decades. PPT Program efforts to better understand human fall mechanisms and develop innovative and cost-effective solutions, such as modified protective equipment, along with recent advances in virtual reality, wireless sensing, and remote measurement technologies, have enabled researchers to more effectively evaluate engineering interventions for fall protection.

Support from stakeholders—including the MSA, the American Society of Safety Engineers (ASSE), the International Safety Equipment Association (ISEA), the International Society for Fall Protection (ISFP) and California OSHA—has helped the PPT Program obtain resources to

advance scientific knowledge on formulating harness-sizing schemes and harness designs for various populations, including women and minorities, to assure the required level of protection, productivity, and comfort of harnesses to workers. Active participation from MSA and DBI-SALA Fall Protection Inc. is facilitating the transfer of research to industry practice.

What's Next?

Reduction of fall incidents requires

- 1) a full-scale analysis of all the data resources to determine the types of injuries that are occurring and the causes of these injuries
- 2) full-scale analyses of existing protective measures for falls
- 3) the transfer of current knowledge on fall *prevention* and *protection* into industrial practices
- 4) further understanding of the biosciences underlying human falls,
- 5) development of innovative *fall-prevention* strategies and improved *fall-protection* technologies,
- 6) research and development of a scientifically comprehensive yet easy-to-use model for fall-incident investigations, worker training to recognize fall hazards, and evaluation of worksite designs for fall-hazard control and
- 7) a public/workforce education campaign on fall prevention and evaluation of effectiveness of fall prevention strategies.

To effectively reduce the number of fall incidents nationally, research should focus on construction, service, and wholesale and retail trade industries. Industry, labor, and professional organizations understand the need for, and have a desire to support fall-prevention research, but have difficulty investing in the sophisticated test facilities, integration of multiple science fields, and significant initial research costs required. In truth, no single organization can provide the level of resources needed. The existing rich partnership among NIOSH, health service companies, safety equipment associations, and safety professional societies has laid the foundation for expanding national and international efforts in occupational fall prevention.

Appendix D.6 List of Outputs

Peer Reviewed Publications

Hsiao H, Whitestone J, and Kau T [2006]. Evaluation of fall-arrest harness sizing scheme. *Human Factors* 48. [in press] [129]

Simeonov P, Hsiao H, Powers J, Ammons D, Amendola A, Kau T, Cantis D [2006]. Footwear effects on walking balance at elevation. (submitted to the *Ergonomics*) [130]

Hsiao H, Bradtmiller B, Whitestone J [2003]. Sizing and fit of fall-protection harnesses. *Ergonomics* 46(12): 1233-1258.[131]

Hsiao H, Long D, Snyder K [2002]. Anthropometric differences among occupational groups. *Ergonomics* 45(2): 136-152.[132]

Conference Papers and Presentations

Turner N, Weaver D, Whisler R, Zwiener J, Wassell J [2006]. Suspension tolerance in men and women wearing safety harnesses, presented at the American Industrial Hygiene Conference and Exposition, Chicago, IL, 2006. (Abstract No. 144) [133]

Hsiao H [2005]. Falls Prevention (keynote speech), Slip, Trip, and Fall Symposium, the Ergonomics Society annual conference (UK), 2005.[134]

Hsiao H, Whisler R, Kau T, Zwiener J, Guan J, and Spahr J [2005]. Constructing new harness with charts using 3D Anthropometric Information. *Contemporary Ergonomics* 3:7, April 4 – 7, 2005, Hertfordshire, England.[135]

Pan C, Hoskin A, Lin M, Castillo D, McCann M, Fearn K [2005]. Incidents due to aerial work platforms. Proceedings of XVIIth World Congress on Safety and Health at Work, Orlando, FL, 2005.[136]

Friess M, Rohlf FJ, Hsiao H [2004]. Quantitative assessment of human body shape using Fourier analysis, in proceedings of SPIE—The International Society for Optical Engineering Conference, January 18-22, 2004, San Jose, California.[137]

Hsiao H [2004]. Anthropometric procedures for design decisions: From flat map to 3D scanning. *Contemporary Ergonomics*, proceedings of the Ergonomics Society Conference in April 2004. Boca Raton, FL: CRC Press, pages 144-148.[138]

Lineberry GT, Scharf T, Jameson R, McCann M, Sulecki R, Wiehagen WJ [2002]. An educational intervention for extension ladder set-up and use. In *Power Through Partnerships: 12th Annual Construction Safety and Health Conference*, Proceedings May 21-23, 2002, Rosemont, IL.[139]

- Ramani R, Flick J, Radomsky M, Russell G, Calhoun B, Haggerty J, Kowalski K, Rethi L, Stephenson CM, Wiehagen B, Scharf T [2002]. Hazard recognition: Fall prevention in construction, Best Practices in Occupational Safety and Health, Education, Training, and Communication: Ideas That Sizzle, 6th International Conference, Scientific Committee on Education and Training in Occupational Health, ICOH, In Cooperation with The International Communication Network, ICOH, Baltimore, Maryland, USA, October 28-30, 2002.[140]
- Simeonov P, Hsiao H, Dotson B, Ammons D [2002]. Comparing standing balance at real and virtual elevated environments, Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting 2002, Sep-Oct, 2169-2173.[141]
- Hsiao H, Dotson BW [2000]. Safe work at elevation through virtual reality simulation. NOIRS 2000--Abstracts of the National Occupational Injury Research Symposium 2000, Pittsburgh, PA, October 17-19, 200, Pittsburgh, PA: National Institute for Occupational Safety and Health, 60-61.[142]
- Pan CS, Chiou S [1999]. Slip and fall: Fall protection in construction safety. Industrial and Occupational Ergonomics: Users' Encyclopedia. Cincinnati, OH: International Journal of Industrial Engineering. Apr; :CDROM (1-9).[143]
- Casini V, Lentz TJ [1998]. NIOSH - a resource for occupational health and safety support. Tower Times 4(10):35/37. October 1998. <http://www.natehome.com/98/tt1098.html> [144]
- Bradtmiller B, Whitestone J, Feldstein J, Hsiao H, Snyder K [2000]. Improving fall protection harness safety: Contributions of 3-D scanning. In Scanning 2000—Numerisation 3D, 5th ed. Proceedings of the Industrial Congress on 3D Digitizing, Paris, France, May 24-25, 2000. Dinard Cedex, France: Harbour, pp. 117-128.[145]
- Patents*
- A provisional patent application was filed on July 14, 2006 for a harness accessory which automatically supports a wearer in a sitting position with the knees elevated at a position at or above the hips after a fall (CDC Ref. No. I-002-06).[146]

D.7 Select and Develop Vibration Isolation Devices to Reduce Hand-Arm Vibration Syndrome. (Strategic Goal 3, Objective 8)

Issue

As far back as 1911, scientists associated vibration from hand-held tools with the risk of pain, numbing, and blanching of the fingers, known as vibration white finger. However, even now, many key aspects of the problem are not well understood, hampering efforts to identify worker populations at risk and to design effective control measures.



Figure D.7.1 - A vibrating pneumatic hand-tool operator in the later stages of Hand-Arm Vibration Syndrome

Powered hand-tools such as chipping hammers, grinders, chainsaws, rock drills, road breakers, and riveters are widely used in several industries such as foundries, automobile manufacturing, forestry, construction, mining, and bridge construction. Hand-arm vibration syndrome (HAVS) is one of the major diseases among more than one million U.S. workers exposed to hand-transmitted vibration (HTV). Prolonged, extensive exposure to HTV is strongly associated with HAVS. The most well-known component of HAVS is termed vibration-induced white finger (VWF). Although HAVS has been studied for more than 80 years, the mechanisms of the syndrome are not sufficiently understood. It is still inconvenient, expensive, and technically difficult to accurately measure tool vibration and to assess related exposure factors such as applied forces and postures. The diagnosis of the disease still mainly depends on subjective questionnaires. Many aspects of current risk assessment methods have not been validated. [147]

Operating powered hand-tools such as chipping hammers and rock drills frequently requires forceful and repeated push and grip actions to control the tools and achieve desired productivity. Many of these tools are also known to generate high magnitudes of hand-transmitted vibration. A tight hand-tool coupling imposes high stresses on the anatomical structure of the hand-arm system and impedes peripheral circulation; it also increases hand-arm vibration (HAV) transmissibility.[148] Further studies on HTV exposure and health effects are required. Anti-

1271 vibration gloves are increasingly being used as PPE to help reduce the hazards of hand-
1272 transmitted vibration.

1273 In the late 1980s the first A/V gloves were introduced with viscoelastic glove liners. A Japanese
1274 firm introduced an A/V glove design using an air bladder inflated with a small bellows pump.
1275 Through the years improvements have been made and viscoelastic materials (such as GELFOM
1276 made by Chase Ergonomics Co.)[149] and A/V glove design have been introduced. In 1988,
1277 ANSI introduced the first A/V glove testing standard (ANSI S3.40) [150], but now the ISO A/V
1278 glove standard (EN ISO 10819) governs the vibration isolation glove designs.

1279 **Approach**

1280
1281 *Conduct Research to Reduce Exposure to Hand-arm Vibration Injuries*
1282

1283 The PPT Program on HTV is aimed at:

- 1284 1) conducting comprehensive studies of the biodynamics of the fingers-hand-arm system using
1285 advanced vibration testing and measurement methods, and finite element modeling;
- 1286 2) developing practical and efficient methodologies to measure hand-applied forces and to assess
1287 hand-arm postures when using powered hand-tools;
- 1288 3) understanding the cellular, physiological, and pathological effects of vibration exposure using
1289 animal models;
- 1290 4) using human subjects to determine the acute effects of vibration exposure on physiological
1291 measures such as the vibrotactile perception threshold shift, the thermal perception threshold
1292 shift, and blood circulation changes in the fingers and hand;
- 1293 5) establishing new frequency weightings and dose-response relationships for risk assessments of
1294 the major components of hand-arm vibration syndrome;
- 1295 6) developing more effective vibration measurement methods, devices, and expert systems so
1296 that non-experts can carry out reliable and accurate measurements; and
- 1297 7) investigating the effectiveness of vibration isolation devices such as anti-vibration gloves and
1298 sleeves through tests using an instrumented vibrating handle that simulates specific tools and
1299 vibration characteristics.[147]

1300 NIOSH is pursuing studies to help fill those critical gaps and point to ways for effectively
1301 reducing risks of hand-vibration disorders for employees who use jackhammers, chipping
1302 hammers, power drills, and other vibrating tools. Individually, the studies focus on particularly
1303 complex, challenging areas where new data likely will advance the understanding and prevention
1304 of job-related hand-vibration disorders. Collectively, the studies constitute a balanced,
1305 interlocking program of strategic research. Current projects include:

- 1306 • Using advanced microscope technologies to determine if adverse effects from vibrating
1307 tools can be predicted from physical changes in the capillaries at the base of the
1308 fingernail cuticle, too small to see with the naked eye.
- 1309 • Developing a computer model of stress and strain on the fingertips from vibrating tool
1310 handles, as measured by the degree to which the soft tissues of the fingertips are
1311 compressed or displaced by the vibrating handle, as another potential way to flag early
1312 warning of adverse effects.

- Assessing infrared thermal imaging of the hands as a potential method for identifying the presence and severity of hand-arm vibration syndrome. This is based on research showing that the temperature of the fingertips – after exposure to cold – returns to normal more slowly in a person with hand-arm vibration syndrome than in a person without HAVS.
- Designing a test method for simultaneously measuring the impact of a chipping hammer bit and the degree of vibration from the handle. The method would give scientists a way to determine if control measures effectively minimize vibration without diminishing the chipping hammer's performance.
- Investigating the effectiveness of anti-vibration gloves through tests using an instrumented vibrating handle that simulates specific tools and vibration characteristics.

Contribute to Standards to Reduce Exposure to Hand-arm Vibration Injuries

Anti-vibration gloves have been used to help reduce the severity of vibration exposure. The vibration attenuation performance of conventional and anti-vibration gloves has been widely evaluated using the method outlined in ISO-10819 (1996).[151] Many studies have recognized shortcomings of the standardized method, specifically measurement errors caused by geometric misalignments of the palm-held adaptor and inter- and intra- subject variability. Additional errors may also arise from dynamic interactions among the human hand, adaptor, handle and the electro-magnetic vibration exciter. A systematic analysis of error sources could yield improved methods to assess the gloves' anti-vibration potentials.[152]

Evaluate Technologies to Reduce Exposure to Hand-arm Vibration Injuries

Although the importance of hand coupling force has been recognized, the current international HAV assessment standard (ISO-5349-1, 2001a) [153] has not accounted for this factor. This is partially due to the lack of a practical method for quantifying the hand coupling force. Several approaches have been proposed to modify the assessment methodology to include the hand force effect. An international committee has drafted a working document in an effort to develop a generally acceptable method for quantifying hand coupling forces (ISO/WD 15230, 200 lb).[154] While it is technically feasible to accurately measure hand forces using instrumented handles or flexible force sensors, quantifying hand forces applied to tools in the workplace remains a formidable task. As a convenient approach, a psychophysical technique called magnitude-reproduction or the force matching method has been used to quantify various hand and arm forces. However, using this technique for measuring hand forces applied to vibrating tools has not been seriously studied. To examine and refine this technique, NIOSH researchers have planned a series of systematic studies. [148]

The ISO-10819 (1996) recommends design of an instrumented handle and specifies a palm-held adapter for laboratory assessment of anti-vibration performance of gloves. Although these designs and test procedures have been widely used, many studies have acknowledged a relatively high degree of measurement error associated with the test fixture design. The dynamic behavior of the recommended test fixture (handle and adapter), coupled with the human hand, tends to alter the standardized vibration inputs to the glove and result in potential undocumented test

errors. In a PPT Program study, the dynamic characteristics of the handle-adaptor system were investigated to identify their contribution to the potential measurement errors, and an improved design of the instrumented handle was developed to reduce the potential errors.[155]

International standard ISO 10819 was established to quantify the vibration attenuation characteristics of anti-vibration gloves. One problem that exists with the standard is possible misalignment of the palm adaptor placed underneath the test glove. If the adaptor becomes misaligned, the measured glove transmissibility will be lower than the actual value. A tri-axial accelerometer was installed in the adaptor and used as the basis for providing visual feedback of the adaptor alignment to the test subjects.

A NIOSH study was conducted to test the hypothesis that adaptor misalignment could be reduced by providing feedback to the test subjects. Eight male volunteers (mean age 24.8 yr) each performed two sets of tests: the standard ISO 10819 glove test and the modified version. Three different anti-vibration gloves were tested. Glove transmissibility and adaptor misalignment were calculated for each glove. A three-way analysis of variance was used to analyze the results. A comparison of the two testing methods showed that the modified glove testing method did reduce misalignment significantly, which, in turn, resulted in an increase in the measured glove transmissibility. The proposed method greatly improved the standard deviation of transmissibility and made the test results more consistent.[156]

A test method based upon total effective acceleration transmissibility (TEAT) is proposed to study the vibration isolation performance of anti-vibration gloves. The vibration transmission characteristics of three different gloves are investigated under predominantly axial vibration using the proposed method and the procedure outlined in ISO-10819. The measured data were analyzed to illustrate the errors arising from misalignments of the response accelerometer within the palm-held adaptor, unintentional non-axial vibration caused by the vibration exciter and dynamics of the coupled hand-handle system. Variations could cause measurement errors in excess of 20%. The vibration transmission characteristics of selected gloves, evaluated using the proposed method, were compared with those derived from the standardized method to demonstrate the effectiveness of the TEAT approach. It was concluded that the TEAT method can account for the majority of the measurement errors and yield more repeatable and reliable assessments of gloves.[157]

The effectiveness of the transfer function method was examined using two typical vibration-attenuation gloves when used in conjunction with two different pneumatic chipping hammers. Six adult male subjects participated in the experiments involving measurement of gloves transmissibility while operating the selected tools. A comparison of the measured vibration transmissibility with the predicted values revealed that the transfer function method provides a reasonably good prediction of the vibration isolation performance of the gloves. The differences between the predicted and measured mean values of the weighted transmissibility were small. It was concluded that the transfer function method can serve as an effective and convenient approach for estimating the effectiveness of anti-vibration gloves when used with pneumatic chipping hammers. A pneumatic chipping hammer is considered to represent a critical case for the evaluation of the method because they are typical percussive tools that generate impact

vibration, and the method may also be widely employed to predict anti-vibration glove performance when used with many other vibrating tools.[158]

A methodology to estimate vibration isolation effectiveness of anti-vibration gloves as a function of specific tools' handle vibration is proposed on the basis of frequency response characteristics of the gloves. The handle vibration spectra of six different tools were synthesized in the laboratory and attenuation performances of two different gloves were characterized under tool vibration, and M- and H-spectra defined in ISO-10819 (1996). The vibration characteristics of gloves were measured using three male subjects in the laboratory under different excitation spectra. The results suggested that tool-specific vibration isolation performance of a glove cannot be derived from the standardized M- and H-spectra and that frequency response characteristics of gloves were relatively insensitive to the magnitude of vibration but strongly dependent upon visco-elastic properties of the glove materials. It was concluded that the isolation effectiveness of gloves for selected tools can be effectively predicted using the proposed methodology.[159]

The instrumented handle and a palm-held adapter recommended in the ISO 10819 standard were evaluated systematically to identify their potential contributions to the overall measurement errors. The results revealed a nonuniform distribution of vibration along the handle surface. The results also revealed the presence of considerable magnitudes of nonaxial source vibration caused by the nonaxial nature of the feed force imparted by the human hand. An alternate design of the handle achieved a more uniform distribution of vibration. Three alternative methods were proposed to minimize the contributions due to adapter misalignment and the nonaxial source vibration. An error contour method was proposed to predict the influence of the dynamic features of a handle on the measurement of effective vibration. The characterization methods developed in this study may also be applicable to other types of instrumented handles for the study of hand-arm vibration.[160]

In another PPT Program study, the effectiveness of anti-vibration gloves was investigated through examination of their vibration transmission characteristics. The findings indicated that only a few glove designs can reduce vibration transmitted to the palm of the hand, and the effectiveness of anti-vibration gloves depends upon the tool or the vibration spectrum. Moreover, the anti-vibration gloves yield considerably better vibration isolation when used with high frequency tools than that attained with low frequency tools. The assessment and prediction methods could aid in the selection of appropriate anti-vibration gloves for different tools and working conditions.[161]

Several technical difficulties have been associated with test and evaluation methods for assessing the vibration isolation effectiveness of anti-vibration gloves. The effectiveness of the gloves for specific powered hand-tools can be assessed through measuring acceleration on the head of the third metacarpal or at the wrist. In the present study, the reliability of these on-the-hand measurement methods is evaluated through assessing the vibration transmissibility of gloves while operating chipping hammers. Two different methods, with and without the prior knowledge of tool vibration, for deriving the transmissibility of the gloves are also evaluated. The study used an air bladder glove and a gel-filled glove, two chipping hammers, and feed forces in the 50-200 N range. Six male volunteers were used as test subjects. The transmissibility of the gloves is also estimated using a total vibration transfer function method. The results

suggest that the on-the-hand methods offer some unique advantages over the palm adapter method outlined in ISO-10819, but they suffer from poor repeatability when a high degree of tool vibration variability is observed, especially if the tool vibration is not measured and used for the assessment. Glove transmissibility measured at the third metacarpal is more repeatable than that derived from the measurements at the wrist. Agreements were observed between the predicted and measured transmissibility values of the air glove. However, the measured transmissibility values for the gel-filled glove suggest that it may perform better than as predicted using the transfer function method. [162]

In 2004, PPT Program conducted a study to determine the vibration isolation effectiveness of a typical (air bladder) anti-vibration glove as a function of vibration frequency, and to investigate the effects of hand-tool coupling action and applied force level on the effectiveness. Six male volunteers were used in the study. A palm adapter method similar to that recommended in the current ISO standard for anti-vibration glove testing (ISO-10819, 1996) was used to measure the transmissibility of the glove. Three different handgrip actions (grip-only, push-only and combined grip and push), three force levels (50, 75 and 100 N), and a broad-band random spectrum were used in the experiment. This study found that the effectiveness of the glove generally increased with an increase in vibration frequency, while the glove did not provide any effective vibration isolation at frequencies less than or equal to 25 Hz. Under the same force level, the push-only action produced the greatest vibration attenuation while the grip-only action resulted in the lowest glove performance among the three actions. Increasing the force tended to increase vibration transmissibility at low frequencies (31.5 Hz), while transmissibility decreased at the middle frequencies (63 - 250 Hz).[163]

In 2005, a PPT Program study aimed to identify major individual factors that are directly associated with the effectiveness of anti-vibration gloves. This study found that the vibration transmissibility of the glove was reliably correlated with the apparent mass in the frequency range of 40-200 Hz; and that the glove became more effective when the apparent mass was increased. This study further identified the effective stiffness of the hand-arm system at frequencies from 63 to 100 Hz as the key factor that influenced the biodynamic response and the glove transmissibility measured at the palm of the hand.[164]

In a 2005 study, the PPT Program proposed an alternative method to assess the vibration isolation effectiveness of gloves using the biodynamic responses of the bare- and gloved-hand-arm system exposed to vibration. The laboratory experiments were performed with five human subjects using a typical anti-vibration air bladder glove subjected to a broad-band random vibration spectrum in conjunction with a specially designed instrumented handle. The measured data were analyzed to derive the biodynamic responses of the bare as well as gloved human hand-arm system in terms of the apparent mass and the mechanical impedance. The two biodynamic responses were applied to estimate the vibration isolation effectiveness of the glove. The validity of the proposed concept was examined by comparing the estimated vibration transmissibility magnitudes of the glove with those obtained using a palm adapter method. The comparison of the results suggests that the proposed method offers a good alternative for estimating glove vibration transmissibility. The measured data and the proposed method based upon the biodynamic responses were further used to investigate the effect of the palm adapter on the vibration transmissibility of the glove. The results suggest that the presence of the palm

adapter between the subject's palm and the glove may not alter the basic trends in the transmissibility response, but it would affect the transmissibility magnitudes in the middle- and high-frequency ranges. A distinct advantage of the proposed method is that it eliminates the use of an adapter in assessing the vibration isolation effectiveness of the gloves.[165]

The hand-tool coupling force in the operation of a vibrating tool is generally composed of applied force (AF) and biodynamic force (BF). There is interest in quantifying the coupling force. The objectives of this study are to develop an effective method for estimating the BF and to investigate its fundamental characteristics. The results indicate that the BFs depend on both the tool vibration spectrum and the biodynamic properties of the hand-arm system. The dominant BF frequency component is usually at the same frequency as the dominant vibration frequency of each tool.[166]

A vibration transfer function method for estimating the tool-specific performance of anti-vibration gloves was proposed to help select appropriate gloves for particular tools and to assess the potential risks posed by tool vibration. A PPT Program study evaluated the validity of the method by comparing the predicted vibration transmissibility with the measured value. Two typical vibration-attenuating gloves (air-bladder and visco-elastic material gloves) were used in the study. Two series of experiments were performed for the evaluation. In the first series, the isolation efficiency of selected anti-vibration gloves was evaluated in the laboratory under synthesized handle vibration spectra of six different tools. The second series of tests involved the measurement of the glove transmissibility while operating two different pneumatic chipping hammers. The results of the study showed agreements between the predicted and measured acceleration transmissibility values of the candidate gloves, thus the transfer function method provided a good estimate of vibration attenuation performance of gloves for specific tools.[167]

Output and Transfer Highlights

Systematic studies have created several new concepts and methodologies for studying HTV exposure and health effects, generated new knowledge of the biodynamics of the system, proposed new frequency weighting for exposure quantification, developed new anti-vibration glove test methods and medical test devices, enhanced understanding of the disorders and diagnostic methods, proposed alternative tool tests, and improved vibration and force measurement methods. This program has led to many conference presentations, one article in a trade journal, and more than 40 peer-reviewed journal papers. Our instrumented handle developed from this program has been marketed as a commercial product. NIOSH researchers have helped develop another commercial product: a novel 3-D HTV test system. Our automation nail press test has been patented. The knowledge generated from this program has directly influenced the revisions and/or developments of several international standards. The knowledge has also been used to provide consulting service and health hazard evaluation (HHE) for workplaces.[147]

Intermediate Outcomes

The results of NIOSH studies have been used to help the developments/revisions of ISO standards. Specifically, ISO/FDIS-15230 (2006) on hand force measurements includes three

NIOSH studies. A preliminary revision of ISO 10819 (1996) on glove test includes four NIOSH studies. NIOSH researchers are also taking a leading role in revising ISO 10068 (1998) [168] on biodynamic response, which is associated with another standard (ISO 13753, 1999) [169] on glove material test.

What's Next?

Several important issues and problems in the biodynamic measurement have been identified and resolved, which has significantly helped improve the reliability and accuracy of the experimental data. The results reported in recent years suggest that, from the point of view of biodynamics, the frequency weighting specified in ISO 5349-1 (2001) overestimates the low frequency effect but underestimates the high frequency effect on the ringers and hand. It is anticipated that the further studies of the biodynamics of the system will eventually lead to establishment of a robust vibration exposure theory.[170]

The glove test method specified in ISO 10819 (1996) is based on the measurement of the vibration transmitted to the palm of the hand. The isolation effectiveness of the glove for the fingers could be dramatically different from that for the palm. Further studies plan to develop an effective method to assess the effectiveness of the glove for finger protection. Alternative methods for protecting the fingers and hand will be explored.

Appendix D.7 List of Outputs

Peer Reviewed Publications

Bernard B, Nelson N, Estill CF, Fine L [1998]. Editorial response: The NIOSH review of hand-arm vibration syndrome: Vigilance is crucial. *J Occup Environ Med.* 40(9):780 785.[171]

Dong RG, McDowell TW, Welcome DE, Rakheja S, Caporali SA, Schopper AW [2002]. Effectiveness of a transfer function method for evaluating vibration isolation performance of gloves when used with chipping hammers. *Journal of Low Frequency Noise, Vibration, and Active Control.* 21(3):141 156.[158]

Dong RG, Rakheja S, Smutz WP, Schopper A, Welcome D, Wu JZ [2002]. Effectiveness of a new method (TEAT) to assess vibration transmissibility of gloves. *Int J Ind Ergon.* 30(1):33 48.[157]

Dong RG, Rakheja S, Smutz WP, Schopper AW, Caporali SA [2003]. Dynamic characterization of instrumented handle and palm-adaptor used for assessment of vibration transmissibility of gloves. *J Test Eval.* 31(3):234 246. [160]

Dong RG, Welcome DE, McDowell TW, Rakheja S [2005]. Estimation of the transmissibility of anti-vibration gloves when used with specific tools. *Noise Vib Worldw.* 36(9):11 20.[167]

Dong RG, McDowell TW, Welcome D, Barkley J, Warren C, Washington B [2004]. Effects of hand-tool coupling conditions on the isolation effectiveness of air bladder anti-vibrations gloves. *J Low Freq Noise, Vib Active Control.* 23(4):231 248.[163]

Dong RG, McDowell TW, Welcome DE, Smutz WP [2005]. Correlations between biodynamic characteristics of human hand-arm system and the isolation effectiveness of anti-vibration gloves. *Int J Ind Ergon.* 35(3):205 216.[164]

Dong RG, Rakheja S, McDowell TW, Welcome DE, Wu JZ, Warren C, Barkley J, Washington B, Schopper AW [2005]. A method for assessing the effectiveness of anti-vibration gloves using biodynamic responses of the hand-arm system. *J Sound Vib* 282(3-5):1101 1118.[165]

Dong RG, Welcome DE, Wu JZ [2005]. Estimation of biodynamic forces distributed on the fingers and the palm exposed to vibration. *Ind Health.* 43(3):485 494.[166]

Dong RG, Wu JZ, Welcome DE [2005]. Recent advances in biodynamics of human hand-arm system. *Ind Health.* 43(3):449 471.[170]

NIOSH [1990]. Notice to Readers: Availability of NIOSH criteria document on hand-arm vibration syndrome. *MMWR.* May 18, 1990 39(19):327.[172]

Rakheja S, Dong R, Welcome D, Schopper AW [2002]. Estimation of tool-specific isolation performance of antivibration gloves. *Int J Ind Ergon.* 30(2):71 87.[159]

1607
1608 Smutz WP, Dong RG, Han B, Schopper AW, Welcome DE, Kashon ML [2002]. A method for
1609 reducing adaptor misalignment when testing gloves using ISO 10819. *Ann Occup Hyg.*
1610 *46(3):309-315.*[156]
1611
1612 *Conference Papers*
1613
1614 Dong-RG; Smutz-WP; Rakheja-S; Schopper-AW; Welcome-D; Wu-JZ [2001]. Alternate
1615 methods for assessment of vibration attenuation performance of gloves. 9th International
1616 Conference on Hand-Arm Vibration, June 5-8, 2001, Nancy, France. Paris, France: Institut
1617 National de Recherche et de Securite (INRS), Jun:1-2.[152]
1618
1619 Dong RG, Rakheja S, Smutz PW, Schopper AW, Caporali SA, Stone S, Bader J [2001].
1620 Dynamic characteristics of the instrumented handle and adapter recommended in the ISO 10819,
1621 1996. 9th International Conference on Hand-Arm Vibration, June 5-8, 2001, Nancy, France.
1622 Paris, France: Institut National de Recherche et de Securite (INRS), Jun:1-2.[155]
1623
1624 Dong RG, McDowell TW, Welcome DE, Rakheja S, Smutz WP, Warren C, Wu JZ, Schopper
1625 AW [2003]. Effectiveness of anti-vibration gloves. *Working Partnerships: Applying Research to*
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